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BY

F. J. WARTH, B.Sc., M.Sc

Agricultural Chemist to the Government of Burma, Mandalay

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[Received for publication on 10th February, 1919.]

PART I. INTRODUCTORY.

THE experimental work which has been done in connection with acidic properties of soils may be fairly fully considered under the two following heads :—

(*a*) Effects of neutral salts on soils.

(*b*) Effects of lime as hydrate carbonate or bicarbonate on soils.

The action of neutral salts on soils is generally explained as an adsorption phenomenon. Amongst the strong arguments in support of this view, the following may be mentioned. The equilibrium between the salt solution and soil has been shown to follow very accurately the adsorption isotherm.[1]

The soil can absorb other substances with which it is not suspected of reacting chemically to an appreciable extent. Some dyes, oxalic and other organic acids fall under this head.[2]

[1] Patten and Cameron; *Journ. Phys. Chem.*, 1907, 581. Parker; *Journ. Agric. Res.*, 1913, 179. Aberson; *Kolloid Z.*, 1912, X, 13. Wiegner; *J. f. Landw.*, 1912, 111.

[2] Hanley; *Journ. Agric. Sci.*, 1914, 58. Patten and Cameron; *Loc. cit.* Prescott; *Journ. Agric. Sci.*, 1916.

The experiment of Pratolongo (quoted by Prescott) on the absorption of phosphoric acid by calcareous and non-calcareous soils supports in a striking manner the adsorption theory.

On the other hand, it has been known from the earliest days of these soil studies that the action of neutral salts leads to a substitution of bases in practically theoretical chemical proportions.[1]

Such a substitution is generally considered to be a chemical reaction.

Hall and Gimingham[2] have shown that, within the ranges of concentration tested, the action of ammonium chloride on soil follows the law of mass action, and must therefore be considered a purely chemical reaction.

The acidity developed when certain soils are treated with neutral salts may be explained as an adsorption phenomenon because the equilibrium follows the usual adsorption isotherm. The acidity has, however, been traced generally to the presence of aluminium salts in solution[3], and it must be admitted that their presence suggests a more fundamental change than purely physical adsorption, unless our views regarding the constitution of some aluminium silicate compounds require to be modified. This does not seem unlikely.

Lachs and Michaelis[4] have shown that many of the typical absorption phenomena of soils, including substitution of bases by the action of neutral salts, can be reproduced by charcoal, the conclusion being that soil acts similarly to the typical adsorbing medium charcoal.

The discussion over this debated ground is simplified if we admit, as is unquestionably the case, that, in the reacting liquid, chemical changes undoubtedly occur, and that the reaction therefore is always purely chemical in one sense. The undecided point is whether the displaceable bases in the soil occur (*a*) as true compounds or less definite additive compounds, or (*b*) in a purely physically adsorbed state.

It is perhaps from further study of the so-called acid soils, in which the absorbing power of the soil for bases is unsatisfied (Daikuhara), that more definite information on this point may be expected.

In these soils neutral salts effect very little displacement (except of alumina), nor has any appreciable direct absorption of base with equivalent liberation of mineral acid been observed.

[1] Way; 1850. Peters; 1860. Parker; *Loc. cit.* Rice; *Journ. Chemi. Soc.*, 1916, A—1, 360.

[2] Hall and Gimingham; *Journ. Chem. Soc.*, 1907, 677.

[3] Conner; *Journ. Soc. Chem. Ind.*, 1916, 551. Rice; *Loc. cit.* Daikuhara; *Journ. Soc. Chem. Ind.*, 1914, 877.

[4] *Z. f. Electroch.*, 1911, 17—1.

Such soils, however, readily absorb bases from alkaline liquids including lime as hydrate carbonate and bicarbonate, and the mode of this absorption is the crucial question.

Lime, as hydrate carbonate or bicarbonate, has been used in laboratory soil tests, principally to discover empirical laboratory processes which would give lime requirement figures comparable either with plant growth in field and pot cultures or with azotobacter developments.[1] There is scope therefore for a more full study of the absorption of lime by soils.

This has been attempted in the experiments described in the present paper by acting upon soils with calcium bicarbonate solutions containing varying amounts of carbonic acid.

The experiments were carried out in connection with an enquiry into the nature of certain types of soil acidity in Burma. It was thought that if the organic and inorganic soil constituents possessed decidedly different powers of absorbing lime, broken absorption curves would be obtained by these tests, and thus some information obtained regarding the nature of the soil acidity.

The work has shown that absorption is remarkably regular. The results therefore have not helped us in the way hoped for. They have, however, shown up some points regarding lime absorption which are worth recording.

It has been found that the soil and carbonic acid enter into competition for the base and an equilibrium is established which depends upon the concentration of the carbon dioxide in solution.

It is quite possible that the absorption of lime follows the exponential law. Owing to experimental difficulties which will be appreciated later, we have so far not attempted to test this point.

However, whether the absorption does or does not follow this law, the equilibrium between lime, carbonic acid, and soil may still be explained as a chemical reaction. We have for this purpose to assume that colloidal acidic bodies exist in acid soils. It may be noted here that some soils are capable of inverting sucrose solution in a manner analogous to the action of acids.[2] The colloids being of a complex hydrated nature must be, if they are acidic, polybasic acids in which the basicity is so high that we have what is equivalent to a continuous series of acidic bodies of increasing strength.

[1] Veitch; *Journ. Chem. Soc.*, 1904, A—2, 600. McIntyre and Willis; *Journ. Soc. Chem. Ind.*, 1915, 93 and 438. Hutchinson and McLennan; *Journ. Agric. Sci.*, 1915, 75. Christensen; *Ex. St. Records*, 1917, Vol. XXXVI.

[2] Hanley. *Journ. Agric. Sci.*, 1914, 59.

The neutral colloids of more nearly neutral soils would in the same way not be devoid of acidic properties. Such substances will possess an amphoteric character and will be able under the influence of alkalis to assume a gradation of acid characters.

The action of calcium carbonate on any one member of this continuous series of insoluble acid bodies will be as follows :—

$$\underset{\text{in solution}}{CaCO_3} + \underset{\text{soil acid}}{\text{Insoluble}} \rightleftarrows \underset{\text{lime salt}}{\text{Insoluble}} + \underset{\text{in solution}}{H_2CO_3}$$

The velocities of the direct and reverse reactions will therefore be respectively proportional to calcium carbonate and carbonic acid in solution (the concentrations of soil acid and its lime compound being constants). At the point of equilibrium, therefore, the quotient $\frac{CaCO_3 \text{ in solution}}{CO_2 \text{ in solution}} = R$ will be a constant for this acid.

For each of the acids of the assumed series there will be such a constant. It is evident that with decreasing acid strength the quotient will have an increasing value, the final term being a value for R which would be in equilibrium with solid calcium carbonate. This would be reached when the soil acids have been neutralized with reference to calcium carbonate.

If lime in solution is in excess of the quantity demanded for the quotient R, absorption will take place until the constant has been attained or the acid neutralized.

With lower calcium carbonate, solution-concentration lime must be extracted from this particular lime acid compound, either completely or until solution-concentration rises to R.

The application of this principle to a soil (assumed to contain a continuous series of acids), when treated with bicarbonate solution, leads to the following result :—

The weakest acid in which combination can take place is the one for which R is equal to the ratio $\frac{CaCO_3}{CO_2}$ in solution when equilibrium between soil and solution has been attained.

All the members stronger than this one will have formed lime compounds; the members weaker than this one cannot take up any lime from this solution.

The lime absorbed in this case is the amount required to combine with the acids specified and is therefore a definite quantity. It may be observed that the same amount of lime absorption should be attained using bicarbonate solutions of different initial strengths and also different strengths at the

attainment of equilibrium. The only condition for equal absorption in every case being that, when equilibrium has been established, the ratio $\frac{CaCO_3}{CO_2}$ in solution shall be the same.

If equilibrium is attained when R has a higher value, clearly some of the acids which were not able to absorb lime in the case just considered will be able to do so now. The total lime absorbed by the soil will therefore be more.

The total lime absorbed by a soil should accordingly be a function of the quotient R.

Owing to changes in degree of ionisation and to the fact that we are not dealing with pure calcium carbonate solutions (effect of displacement), it cannot be expected that the value of R will for any given acid remain absolutely constant for all dilutions.

Within the moderate ranges of dilution tested, the differences should be scarcely greater than the errors of experiment.

A reference to the experimental results shows that, as far as they go, the figures of Table II support the assumptions made above.

PART II. EXPERIMENTAL.

1. Description of soils used.

The figures of the accompanying Table I show the composition of the soils :—

Table I.

Laboratory No. of 1916	844	846	845	848	——	867
Name of soils	Hlegu	Hmawbi	Mandalay	Pwinbyu	Hopin	Sahmaw
Insoluble residue ..	73·82	68·47	55·80	59·53	71·39	48·11
Soluble silica ..	11·53	13·11	19·20	12·65	12·37	18·08
Ferric oxide (Fe_2O_3)	1·15	3·62	4·26	5·91	2·85	10·08
Alumina (Al_2O_3) ..	8·29	9·37	14·00	13·93	7·47	14·20
Lime (CaO) ..	0·36	0·32	0·82	0·66	0·58	0·97
Magnesia (MgO) ..	0·07	0·13	0·15	0·21	0·32	0·43
Potash (K_2O) ..	0·25	0·49	0·89	0·99	0·31	0·26
Soda (Na_2O) ..	0·11	0·24	0·30	0·23	0·10	0·11
Sulphuric acid (SO_3)	0·06	0·04	0·06	0·20	0·07	0·08
Phosphoric acid (P_2O_5)	0·02	0·03	0·04	0·13	0·04	0·04
Carbon dioxide (CO_2)	0·03	0·02	0·31	0·12	0·02	0·02
Organic matter + ..	4·62	4·16	4·17	5·44	4·48	7·62
Combined water ..	..	..	..	..	..	..
Total ..	100·00	100·00	100·00	100·00	100·00	100·00
Organic carbon ..	1·3940	0·8780	0·7900	0·9640	1·3130	1·5780
Organic nitrogen ..	0·1162	0·0724	0·0720	0·1100	0·1090	0·1320
Available phosphoric acid.	0·0007	0·0029	0·0106	0·0489	0·0104	0·0065
Available potash ..	0·0064	0·0147	0·0271	0·0275	0·0205	0·0290

The samples are typical of large characteristic soil formations of Lower, Middle and Northern Burma respectively.

(*a*) Hlegu and Hmawbi soils are typical of the leached out soils of Lower Burma. They contain very small amounts of alkaline earths and not much potash. The deficiency of potash is, however, not generally serious compared with the deficiency of lime.

Hlegu is rich in organic matter but this must occur in a remarkably disintegrated state if soil colour is any index. This soil is dark but not black, whilst Hopin giving a lower organic carbon figure is quite black when moist. Both these soils are decidedly acid.

(*b*) Mandalay and Pwinbyu are new soils formed on recent alluvial deposits. They are rich in alkalis and alkali earths. Both are alkaline.

(*c*) Hopin and Sahmaw are typical marsh soils of Northern Burma. They are well supplied with alkaline earths and are rich in organic matter. They contain, however, no more potash than the Lower Burma soils. This fact emphasizes the marshy conditions under which they occur. These soils are also acid.

The test for acidity with litmus paper is worth remarking upon here. If the test paper is placed on the moist soil, Sahmaw and Hopin indicate faint alkalinity. If the paper is placed between two layers of wet soil, Sahmaw shows strong acidity and Hopin weak but definite acidity. If the papers are made to dip into a shallow layer of water on the soil, the free evaporating end of the paper becomes alkaline whilst the part in contact with soil becomes acid.

These peculiarities are clearly due to differences in diffusion of the acidic and alkaline bodies.

Hlegu and Hmawbi show acidity, and the other two soils alkalinity under all the above conditions.

2. Method used in determining lime absorption.

Without going further into the matter at present, it is to be expected that the amount of lime absorbed by a soil from calcium bicarbonate solution will depend upon concentrations of lime and of carbonic acid in solution.

The experimental work, therefore, consisted in determining the amount of lime absorbed from bicarbonate solution containing different amounts of lime and carbonic acid.

A weighed quantity of soil was placed in a bottle. A definite volume of calcium bicarbonate solution of known strength was added. The bottle closed

with greased stopper or bung was placed in a constant temperature bath (at 25°C.), and the contents shaken periodically.

A number of trials showed that equilibrium was not attained in 3 hours. Treatment for 6, 12, and 24 hours gave practically identical results. Six hours' treatment was, therefore, employed throughout these experiments.

To determine the amount of absorption which has taken place, the liquid is filtered and a fraction titrated. We obtain hence the amount of lime left in solution and by difference the amount absorbed.

Filtration is not a desirable process when we are dealing with liquids whose activity depends upon the amount of carbonic acid in solution. This could not be avoided. It is possible, however, to minimize errors by having a tall column of liquid by filtering quickly and by rejecting the first and last fractions of the filtrate. The accuracy of the results of course varied with the amount of absorption.

The corresponding carbonic acid determinations were carried out as follows :—

The bottle containing soil and bicarbonate was treated exactly as above to attain equilibrium. Soil was then allowed to settle. The liquid was syphoned off and a fraction (usually 50 c.c.) run into a 100 c.c. flask containing a measured amount of standard baryta. The flask was filled up to the mark with carbonic-acid-free water, shaken, and allowed to settle 24 hours.

The clear liquid was then syphoned off and a fraction titrated. The loss in strength represented the baryta precipitated as carbonate.

This method was found to give satisfactory results, provided that the strength of baryta was adjusted according to the amount of CO_2 to be determined

A specially adapted syphon to run off the clear liquid at a suitable rate was found to be essential.

By these means the lime remaining in solution and the corresponding were concentration of CO_2 in solution was determined.

3. Absorption of lime by Hlegu and Hmawbi soils.

The absorption was determined with bicarbonate solution of four strengths, each strength of bicarbonate being tested in presence of four different concentrations of carbonic acid. Low concentrations of carbonic acid were avoided to prevent precipitation of lime. For each test 5 grm. of soil were used.

Table II contains the experimental data obtained :—

TABLE II.

Action of calcium bicarbonate solutions on Hlegu and Hmawbi soils.

HLEGU					HMAWBI				
Strength of bicarbonate solution	$CaCO_3$ absorbed	$CaCO_3$ in solution	CO_2 in solution	R	Strength of bicarbonate solution	$CaCO_3$ absorbed	$CaCO_3$ in solution	CO_2 in solution	R
1st series. 100 c.c. = 0·0144 grm. $CaCO_3$	0·0104	0·0040	0·0095	0·421	1st series. 100 c.c. = 0·0138 grm. $CaCO_3$	0·0048	0·0090	0·0086	1·045
	0·0082	0·0062	0·0253	0·245		0·0032	0·0106	0·0182	0·583
	0·0071	0·0073	0·0411	0·177		0·0020	0·0118	0·0288	0·410
	0·0067	0·0077	0·0413	0·182		0·0008	0·0130	0·0356	0·365
	0·0058	0·0086	0·0559	0·154		0·0000	0·0138	0·0497	0·278
2nd series. 100 c.c. = 0·0288 grm. $CaCO_3$	0·0146	0·0142	0·0163	0·871	2nd series. 100 c.c. = 0·0250 grm. $CaCO_3$	0·0064	0·0186	0·0169	1·103
	0·0126	0·0162	0·0317	0·511		0·0044	0·0206	0·0310	0·665
	0·0116	0·0172	0·0462	0·372		0·0030	0·0220	0·0405	0·543
	0·0086	0·0202	0·0572	0·353		0·0026	0·0224	0·0480	0·467
	0·0060	0·0228	0·0770	0·296		0·0014	0·0234	0·0585	0·400
3rd series. 100 c.c. = 0·0436 grm. $CaCO_3$	0·0162	0·0274	0·0295	0·929	3rd series. 100 c.c. = 0·0412 grm. $CaCO_3$	0·0092	0·0320	0·0277	1·155
	0·0136	0·0300	0·0431	0·696		0·0076	0·0336	0·0392	0·857
	0·0112	0·0324	0·0581	0·558		0·0058	0·0354	0·0488	0·725
	0·0096	0·0340	0·0735	0·462		0·0038	0·0374	0·0629	0·595
	0·0102	0·0334	0·0959	0·348		0·0020	0·0392	0·0708	0·554
4th series. 100 c.c. = 0·0582 grm. $CaCO_3$	0·0184	0·0398	0·0400	0·995	4th series. 100 c.c. = 0·0570 grm. $CaCO_3$	0·0100	0·0470	0·0378	1·243
	0·0160	0·0422	0·0532	0·793		0·0076	0·0494	0·0475	1·040
	0·0150	0·0432	0·0581	0·743		0·0056	0·0514	0·0576	0·893
	0·0142	0·0440	0·0678	0·649		0·0052	0·0518	0·0612	0·846
	0·0142	0·0440	0·0682	0·645		0·0042	0·0528	0·0726	0·727
Additional series.	0·0046	0·0048	0·0431	0·111					
	0·0034	0·0061	0·0629	0·097					
	0·0012	0·0018	0·0405	0·044					
	0·0016	0·0040	0·0828	0·048					

It must be noted that the action of calcium bicarbonate is more complex than here assumed. In addition to absorption an appreciable amount of displacement of magnesia and alkalis must take place.

For the present, however, the total alkalinity of the solution in equilibrium with soil is calculated as calcium carbonate.

The results are also shown plotted in curves (Charts I—IV).

It may be noted from these that lime absorption is a regular process, the experimental figures, which are indicated by prominent dots, conforming on the whole closely to definite curves.

How the latter were obtained will be shown later.

For each soil there are four distinct curves corresponding to the four different original strengths of bicarbonate used. The relationship between these four distinct curves will be established later.

In all cases increasing concentration of CO_2 reduces the amount of lime absorbed. With less acid soils it will be seen later that absorption is inhibited by moderate concentrations of CO_2, and with further increase of CO_2 extraction commences. A consideration of this point will give us a clue to the nature of the equilibrium which is established between $CaCO_3$, CO_2, and acid soils.

4. Relation between lime absorption and the quotient R.

From Table II we can take out values for lime absorbed and the corresponding values for R, all determined experimentally.

These figures entered on square paper are shown in Chart V.

Experimental errors are no doubt considerable in a few instances. The effect of dilution is also just noticeable. These defects, however, do not obscure the fact that the figures obtained from four different solution strengths have in this case coalesced to form a single curve.

In other words, lime absorbed is, within these ranges of concentration, a function of the quotient R as was demanded by theory.

The actual relationship existing between R and L, as determined experimentally for these two soils, is given by the smoothed graphs in this chart.

It is from these graphs that the curves of Charts I—IV were calculated as follows :—Taking Charts I and II, Series 4,

with original strength of bicarbonate	= 0·057 grm. per 100 c.c.
Let amount of absorption L be	= 0·008 „ „
Then $CaCO_3$ remaining in solution	= 0·049 „ „

From Chart V we find that when L (lime absorbed) = 0·008, the quotient $R = 1{\cdot}05 = \dfrac{CaCO_3 \text{ in solution}}{CO_2 \text{ in solution}} = \dfrac{0{\cdot}049\ CaCO_3 \text{ in solution.}}{CO_2 \text{ in solution.}}$

Therefore CO_2 in solution = 0·0466 grm. per 100 c.c., *i.e.*, having original concentration 0·057 grm. $CaCO_3$, we find that 0·008 grm. $CaCO_3$ will be absorbed when CO_2 concentration is 0·047 grm. per 100 c.c. In this way one point on the curve of Series IV, Charts I and II, has been calculated. Using other values of L a series of points can be calculated and the curve drawn in.

The curve for the third series in the same charts can be calculated in an identical manner, in this case using the figure 0·0412 for original strength of bicarbonate.

CHART I.

Hmawbi Soil.

Strength of bicarbonate solution in equilibrium with soil.

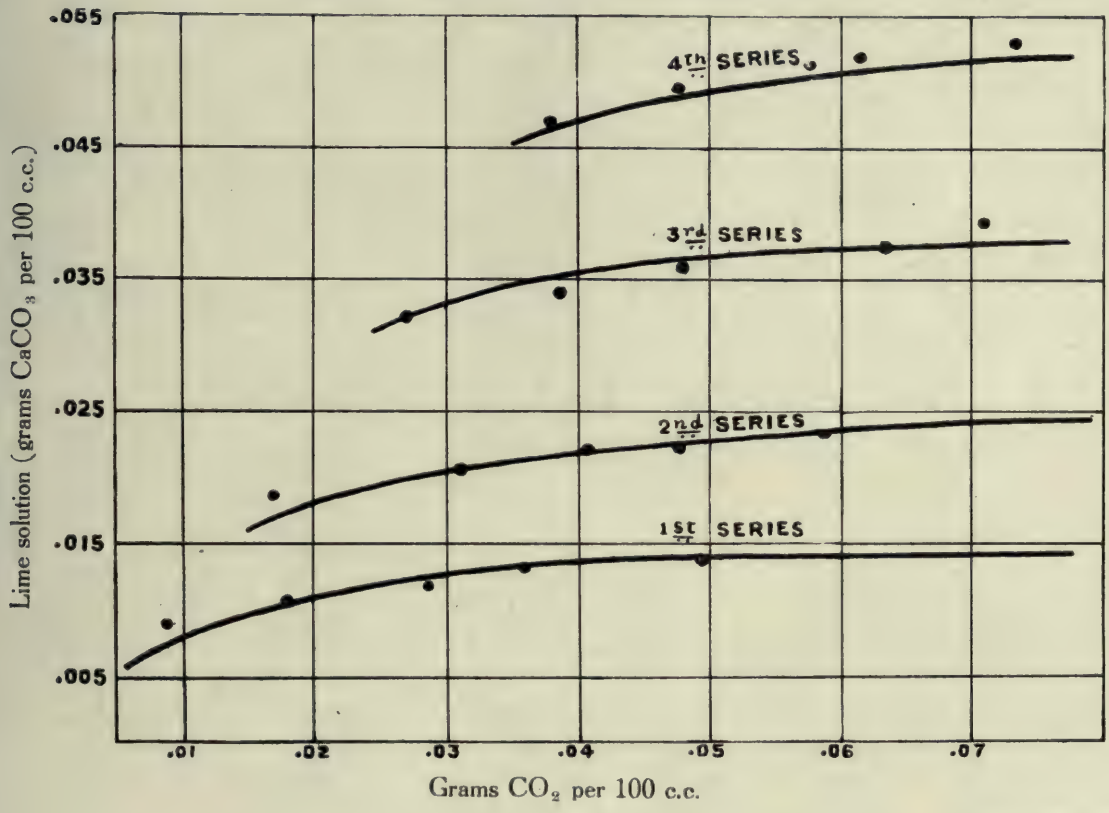


CHART II.

Hmawbi Soil.

Lime absorbed by 5 grams of soil from different strengths of calcium bicarbonate solution.

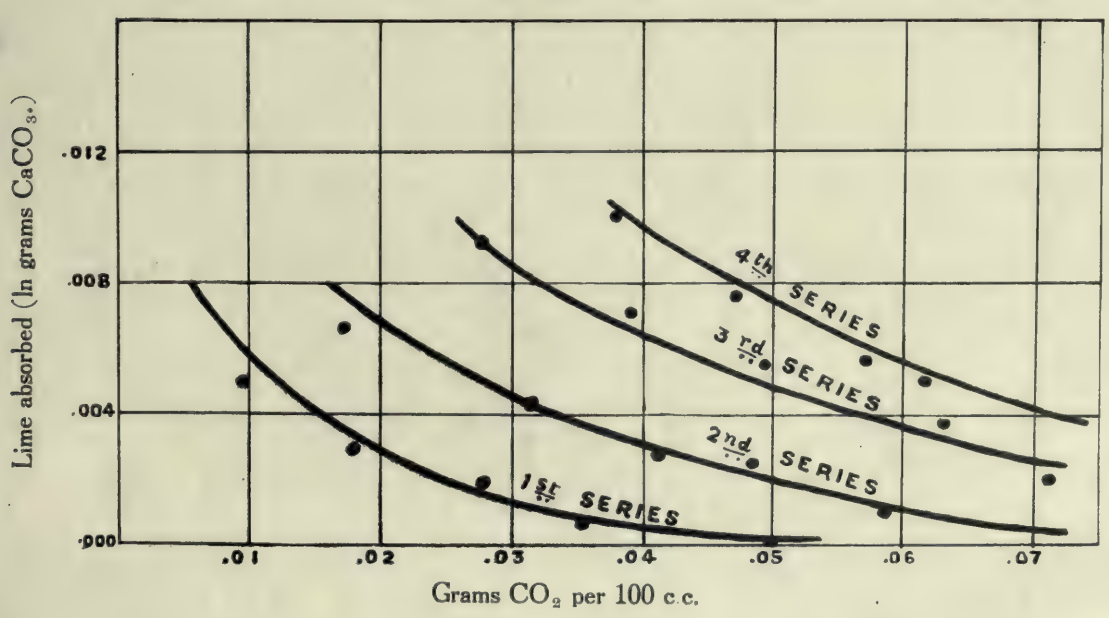


CHART III.

Hlegu Soil.

Strength of bicarbonate solution in equilibrium with soil.

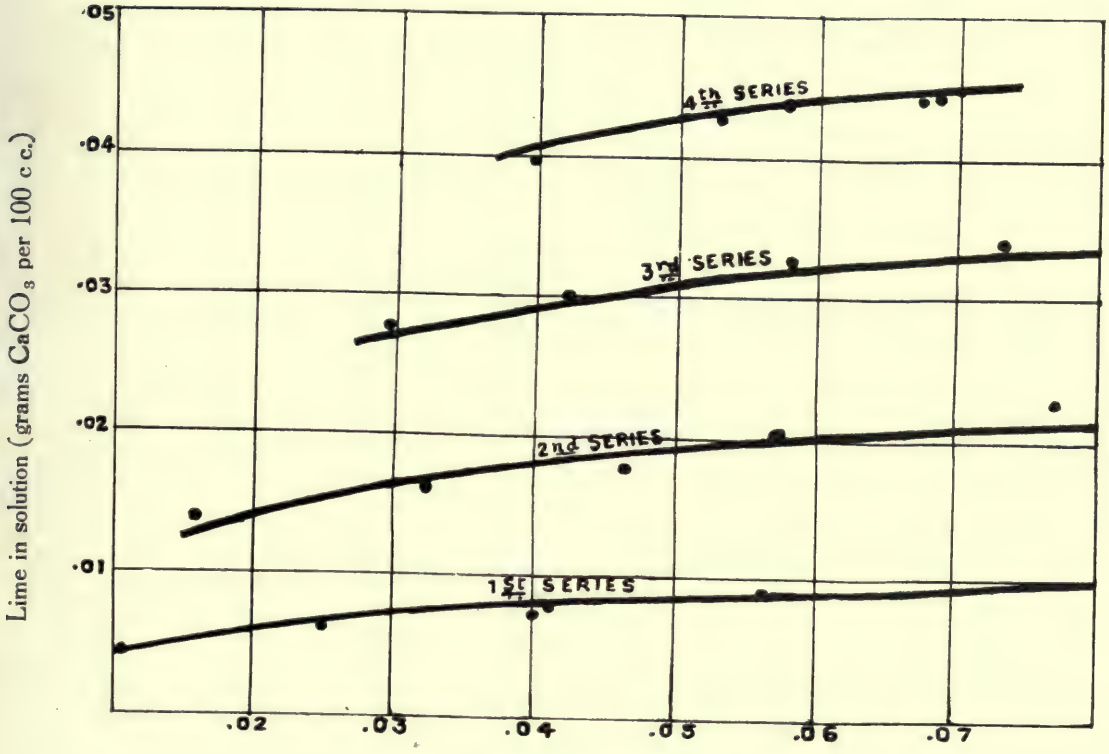
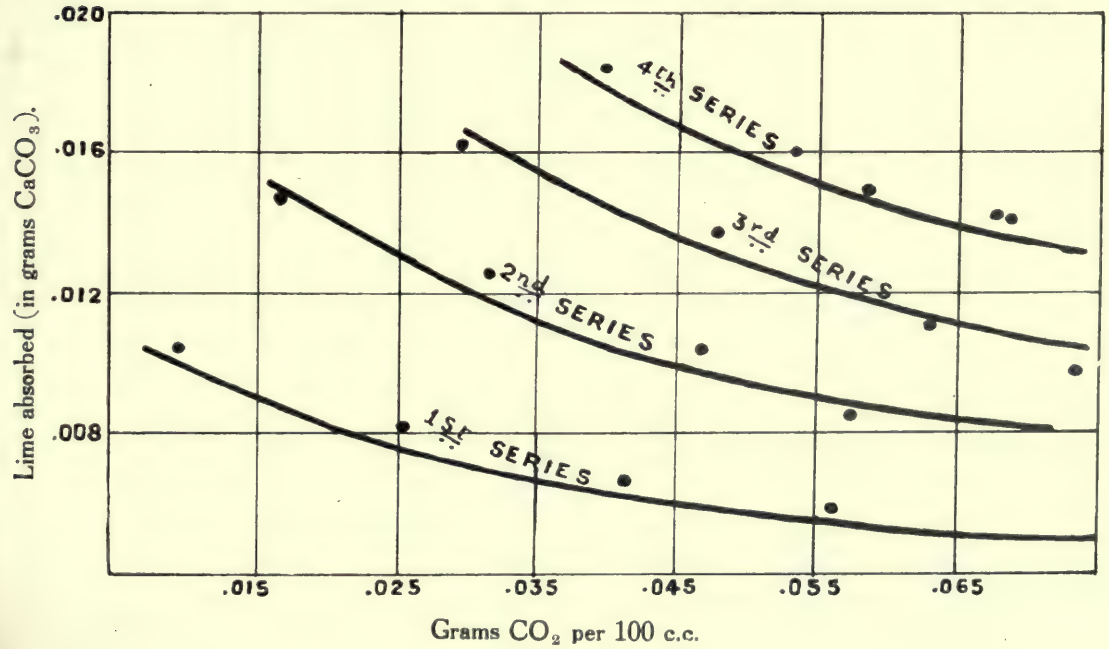


CHART IV.

Hlegu Soil.

Lime absorbed by 5 grams of soil from different strengths of calcium bicarbonate solution.



Relation between quantity of lime absorbed and the quotient R.

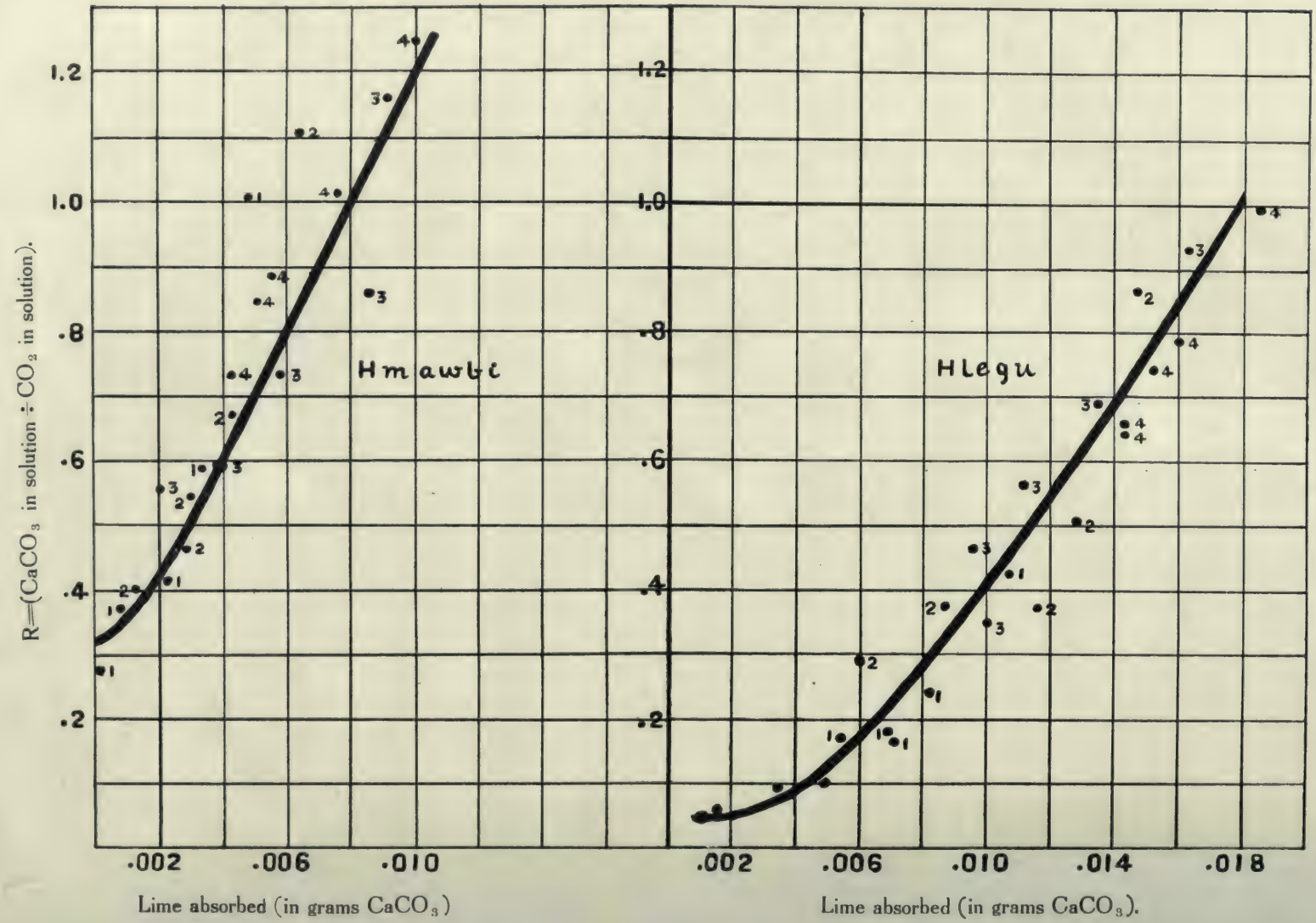


CHART V.

The four distinct curves of Chart I are seen in this way to be related to one another through the single Hmawbi curve of Chart V. Similarly the four distinct curves of Chart III are related to one another through the single Hlegu curve of Chart V.

It may be claimed that the discussion of these results has thrown some light on the avidity of soils for lime.

5. Action of calcium bicarbonate solutions on Sahmaw, Hopin, Pwinbyu and Mandalay soils.

The determinations were carried out as already explained. In this case only two strengths of bicarbonate were tested.

The figures obtained are shown in Table III.

Table III.

Action of calcium bicarbonate solution on Hopin, Sahmaw, Mandalay and Pwinbyu soils.

Hopin				
Strength of bicarbonate solution	$CaCO_3$ absorbed	$CaCO_3$ in solution	CO_2 in solution	R
Series 100 c.c. = 0·0246 grm. $CaCO_3$	0·0032	0·0214	0·1760	1·216
	0·0004	0·0242	0·0268	0·903
	—0·0012	0·0258	0·0352	0·733
	—0·0032	0·0278	0·0506	0·550
	..	..	..	..
Series 100 c.c. = 0·0490 grm. $CaCO_3$	0·0074	0·0420	0·0312	1·346
	0·0036	0·0458	0·0427	1·072
	0·0020	0·0474	0·0497	0·954
	—0·0004	0·0498	0·0642	0·775
	..	..	..	..

Sahmaw				
Strength of bicarbonate solution	$CaCO_3$ absorbed	$CaCO_3$ in solution	CO_2 in solution	R
Series 100 c.c. = 0·0280 grm. $CaCO_3$	0·0071	0·0209	0·0193	1·083
	0·0039	0·0241	0·0344	0·701
	0·0027	0·0253	0·0504	0·502
	0·0016	0·0264	0·0649	0·407
	0·0004	0·0276	0·0966	0·286
Series 100 c.c. = 0·0564 grm. $CaCO_3$	0·0088	0·0476	0·0419	1·185
	0·0066	0·0498	0·0554	0·899
	0·0049	0·0515	0·0632	0·815
	0·0037	0·0527	0·0725	0·727
	0·0027	0·0537	0·0932	0·576

Mandalay				
Strength of bicarbonate solution	$CaCO_3$ excess	$CaCO_3$ in solution	CO_2 in solution	R
Series 100 c.c. = 0·0246 grm. $CaCO_3$	0·0010	0·0256	0·0180	1·422
	0·0072	0·0318	0·0290	1·096
	0·0100	0·0346	0·0352	0·983
	0·0126	0·0372	0·0497	0·730
	..	..	..	..
Series 100 c.c. = 0·0490 grm. $CaCO_3$	—0·0014	0·0480	0·0326	1·472
	0·0016	0·0510	0·0427	1·200
	0·0042	0·0536	0·0506	1·060
	0·0080	0·0574	0·0651	0·880
	..	..	..	..

Pwinbyu				
Strength of bicarbonate solution	$CaCO_3$ excess	$CaCO_3$ in solution	CO_2 in solution	R
Series 100 c.c. = 0·0262 grm. $CaCO_3$	—0·0008	0·0254	0·0169	1·505
	0·0016	0·0278	0·0262	1·061
	0·0042	0·0304	0·0356	0·854
	0·0065	0·0327	0·0493	0·663
	0·0078	0·0340	0·0559	0·608
Series 100 c.c. = 0·0482 grm. $CaCO_3$	—0·0044	0·0460	0·0312	1·474
	0·0006	0·0488	0·0427	1·143
	0·0018	0·0500	0·0488	1·025
	0·0034	0·0516	0·0585	0·882
	0·0044	0·0526	0·0629	0·836

Corresponding values of L and R were determined and absorption curves derived from these exactly as explained in case of Hlegu and Hmawbi.

Charts VI and VII show the curves obtained for Sahmaw and Hopin soils. The results of actual determinations are indicated by points showing that the calculated curves do not depart seriously from the bulk of the experimental figures.

Hopin results are notable in that we find here for the first time negative absorption or extraction taking place.

That there is no appreciable break in the curve in this case is a further proof of the general applicability of the conclusions already arrived at regarding absorption of lime by soils.

6. Comparison of the lime-absorbing powers of the six soils examined.

Once we have determined by experiment the curve $L = f(R)$ for any soil, we can calculate the absorption which would take place with solutions of any strength.

The absorption that would take place from solutions of bicarbonate containing 0·05 grm. $CaCO_3$ per 100 c.c., has been calculated accordingly and the figures are shown graphically in Charts VIII and IX.

These charts enable us to compare more completely the lime absorption power of the soils.

In Chart VIII, the parts of the curve below the zero line indicate the amount of lime extracted from the soil.

Chart IX shows strength of solution remaining in equilibrium with the soil after absorption or extraction has taken place.

The dotted line marks the concentration of the original solution. The distances between the dotted line and curve give the amount of absorption or extraction which has taken place to attain equilibrium.

One important point remains to be discussed. Can these figures be made to yield information regarding the actual lime requirement of these soils ?

If we assume that Pwinbyu is agriculturally a neutral soil, we have to conclude from Chart IX that a neutral soil will absorb no lime from a bicarbonate solution containing 0·05 grm. $CaCO_3$ and 0·045 grm. CO_2 per 100 c.c. liquid. At this equilibrium point we know further that $R = 1·11$. Turning now to Hlegu soil, Chart V shows that when $R = 1·11$ this soil absorbs 0·019 $CaCO_3$, *i.e.*, 0·019 grm. of $CaCO_3$ must be absorbed by Hlegu soil before it can remain in equilibrium with a solution containing 0·05 grm. $CaCO_3$ and 0·045 grm. CO_2 per 100 c.c. Accordingly the lime requirement of 5 grm. Hlegu soil is equal to 0·019 grm. $CaCO_3$.

CHART VI.

Hopin and Sahmaw soils.

Strength of bicarbonate solution in equilibrium with soils.

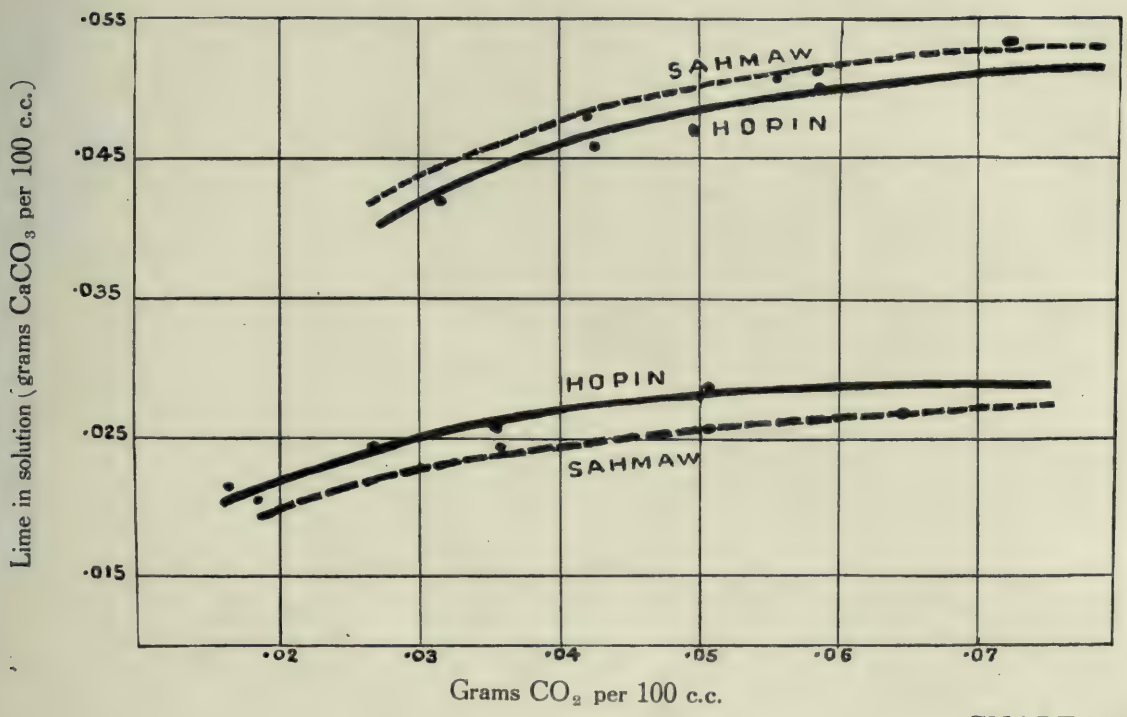


CHART VII.

Hopin and Sahmaw soils.

Lime absorbed by 5 grams of soil from different strengths of calcium bicarbonate solution.

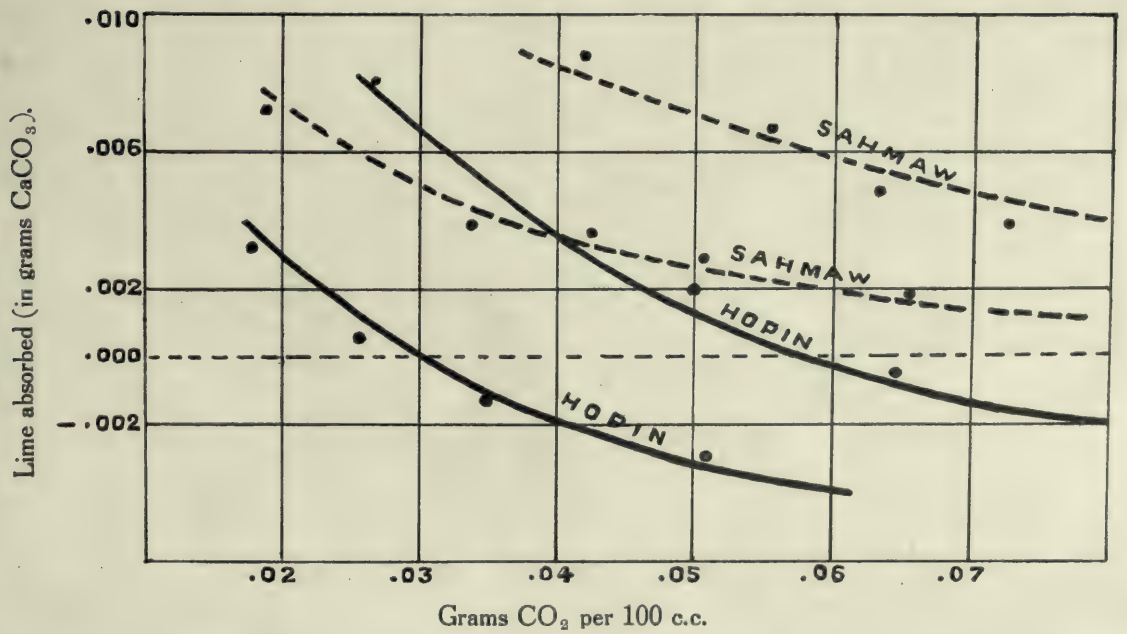
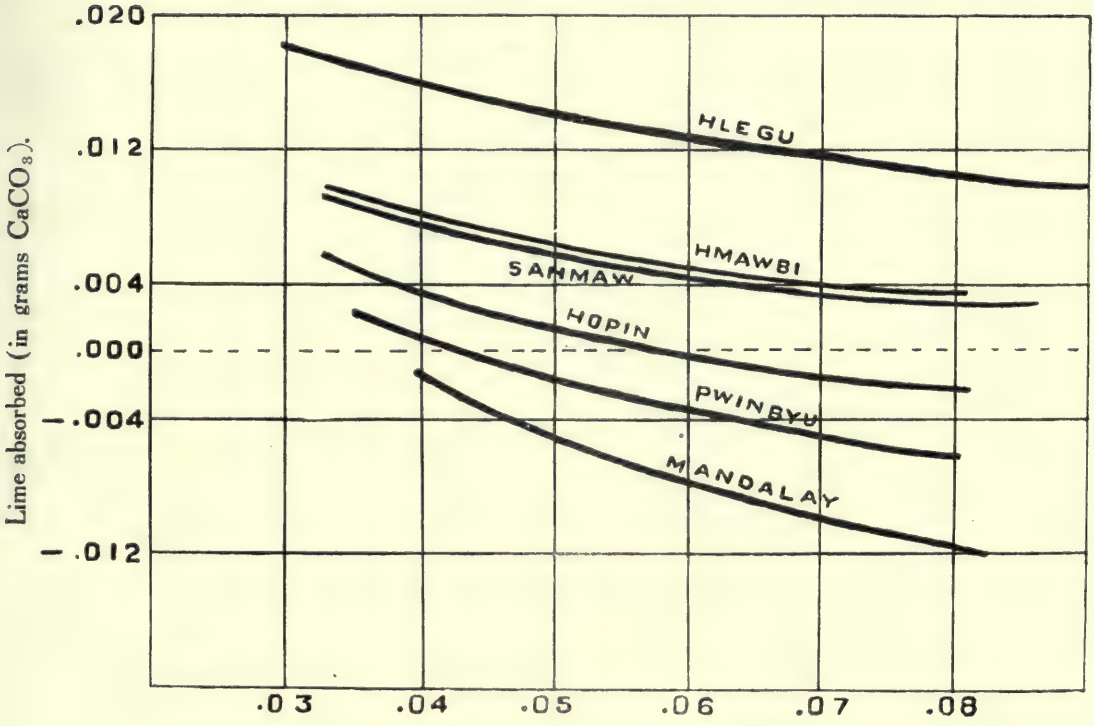


CHART VIII.

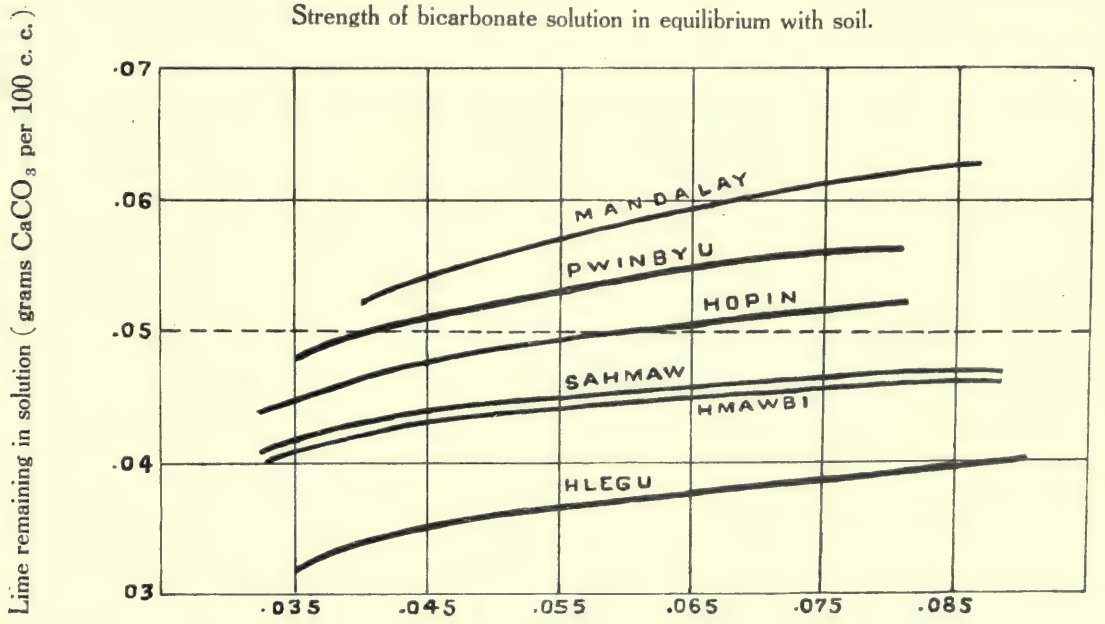
Action of different soils on bicarbonate solution of the same strength
(0·05 grm. $CaCO_3$ per 100 c.c.)
Lime absorbed by 5 grams of soil.



Grams CO_2 per 100 c.c.
The dotted line indicates equilibrium between soil and bicarbonate solution.

CHART IX.

Strength of bicarbonate solution in equilibrium with soil.



Grams CO_2 per 100 c.c.
The dotted line shows original strength of bicarbonate.

Hmawbi in the same way is found to have a lime requirement of 0·009 grm. or 0·18 per cent.

It is perhaps necessary to point out that in these calculations Pwinbyu soil has been assumed to be a typical neutral soil. As a matter of fact Pwinbyu is on the whole to be regarded as a slightly alkaline soil, and, therefore, the equilibrium solution to correspond to a truly neutral soil should contain somewhat more CO_2 than here stated. With this reservation there is no doubt that we have in this method a means of determining soil acidity which deserves some consideration.

7. Total acidity of soils.

Before concluding, the theoretical interest of Charts I—IV deserves some consideration. To enable us to follow them back to their origin further data are required. We must know in the first place the amount of lime which the soil can absorb when in equilibrium with solid $CaCO_3$ in presence of CO_2-free water.

This quantity may be defined as the total soil acidity. We must also know the solubility of $CaCO_3$ in carbonic acid.

The determination of the total soil acidity was made by a process similar to the Veitch method. Several lots of the soil were treated with different quantities of bicarbonate solution and evaporated to dryness. The dry soil was taken up with boiling CO_2-free water, and, after settling, the clear liquid was examined for lime.

The lime content was determined (*a*) by titration, (*b*) by boiling vigorously for two minutes with phenol-phthalein and observing the colour developed. Results are shown in the accompanying Table IV.

Table IV.

Total soil acidity.

HLEGU				HMAWBI			
Bicarbonate used	Reaction of extract		Acidity in grm. $CaCO_3$ absorbed	Bicarbonate used	Reaction of extract		Acidity in grm. $CaCO_3$ absorbed
	Phenol-phthalein	Methyl-orange titration $\frac{N}{50}$ HCl			Phenol-phthalein	Methyl-orange titration $\frac{N}{50}$ HCl	
180	Pink	2·5	∴ Maximum absorption = 0·075 grm. $CaCO_3$	140	Pink	2·4	∴ Maximum absorption = 0·055 grm. $CaCO_3$
160	Pink	2·5		120	Pink	2·5	
140	Faint	1·7		100	Pink	2·0	
120	Very Faint	1·4		80	Very faint	1·8	
100	No	0·9	Stronger acids = 0·050 grm. $CaCO_3$	60	Trace	1·2	Stronger acids = 0·025 grm. $CaCO_3$
80	No	0·7		40	No	0·7	

TABLE IV—*contd.*

HOPIN				SAHMAW			
Bicarbonate used	Reaction of extract: Phenol-phthalein	Reaction of extract: Methyl-orange titration $\frac{N}{50}$ HCl	Acidity in grm. $CaCO_3$ absorbed	Bicarbonate used	Reaction of extract: Phenol-phthalein	Reaction of extract: Methyl-orange titration $\frac{N}{50}$ HCl	Acidity in grm. $CaCO_3$ absorbed
120	Pink	2·5	∴ Maximum absorption = 0·045 grm. $CaCO_3$	140	Pink	2·5	∴ Maximum absorption = 0·055 grm. $CaCO_3$
100	Pink	2·5		120	Pink	2·4	
80	Pink	2·1		100	Pink	2·2	
60	Faint	1·5		80	Pink	2·0	
40	Trace	1·1	Stronger acids = 0·015 grm. $CaCO_3$	60	Faint	1·5	Stronger acids = 0·020 grm. $CaCO_3$
20	No	0·6		40	Trace	0·8	

The soils should of course absorb more lime from $Ca(OH)_2$ solution but for the curves of Charts VIII and IX the $CaCO_3$ figures just determined are the ones we require. The maximum absorption shown in the Charts is calculated as follows for Hlegu soil :—

Soil + 100 c.c. water = 160 c.c. standard bicarbonate.
= 0·080 grm. $CaCO_3$.
Lime in 100 c.c. water = 0·005 grm. $CaCO_3$.
Therefore soil has absorbed 0·075 grm. $CaCO_3$.

These figures are naturally far in excess of the lime requirements of these soils. Their interest at present is solely to give end points to the curves of Charts I—IV.

8. SOLUBILITY OF $CaCO_3$ IN CARBONIC ACID.

J. W. Leather (*Memoirs of the Department of Agriculture, India, Chemical Series*, Volume I, No. 7) made a full series of determinations of the solubility of $CaCO_3$ in water containing increasing amounts of CO_2.

The method used in the present enquiry for lime absorption can be very easily used for determination of solubility of $CaCO_3$ in CO_2 water. A series of determinations was made. In Chart X our figures are plotted against Dr. Leather's graph, showing that the two series of determinations agree very well. Dr. Leather has also determined the solubility of magnesium carbonate in water containing carbonic acid. This cannot be carried out by our method without the aid of corrections in the CO_2 determinations, and has therefore not been attempted.

Solubility of calcium carbonate in carbonic acid.

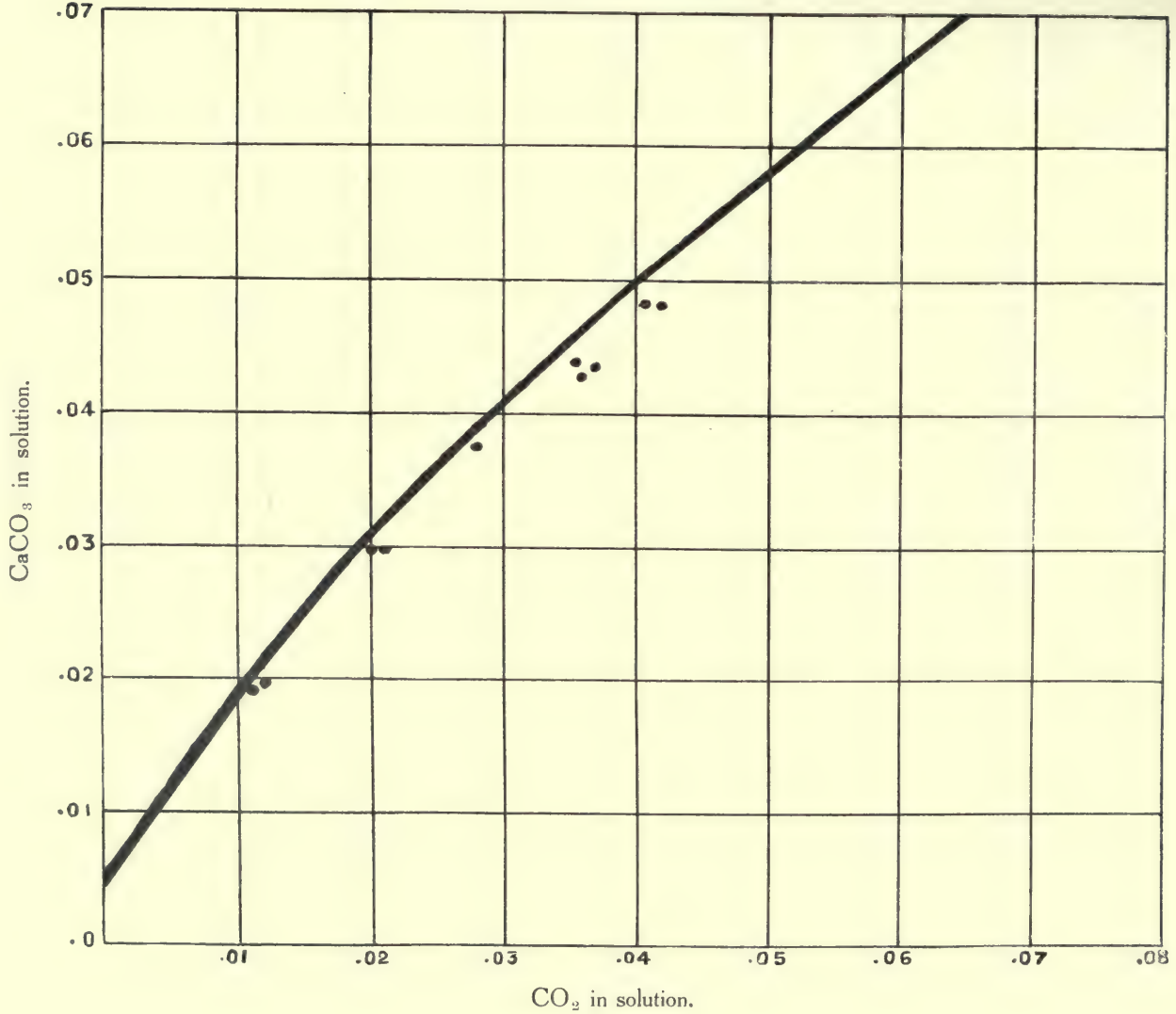


CHART X.

Lime absorption curve. Hmawbi soil (Chart 1.)

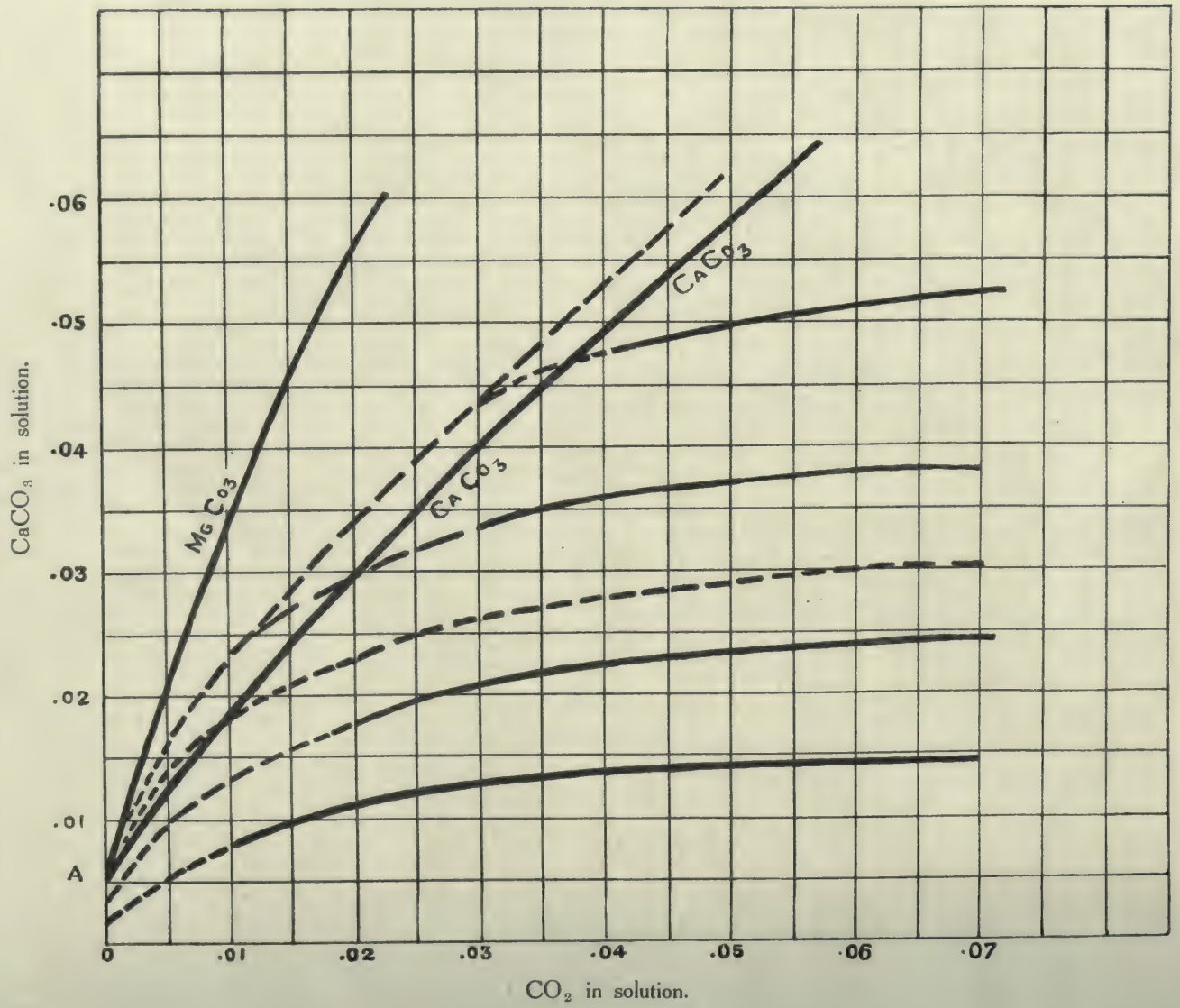


CHART XI.

9. Complete lime absorption curves.

Reference to Chart XI will make the matter clear. We have here in the first place the solubility curves of $CaCO_3$ and $MgCO_3$ in solutions of carbonic acid.

Next we have four incomplete curves for bicarbonate solutions in equilibrium with Hmawbi soil (Charts I—IV).

Between the second and third of these, another curve has been inserted. This has been calculated in the usual way with the aid of the graph in Chart V, using for original strength of bicarbonate 0·0325 grm. $CaCO_3$ per 100 c.c. (*i.e.*, Total soil acidity + $CaCO_3$ soluble in 100 c.c. CO_2-free water).

We know from the total soil acidity determinations that this curve must pass through A. The end of this curve can therefore be drawn in without having to exterpolate values in Chart V. Having completed this, we are in a position to calculate approximately the shape of the undetermined extremities of the other four curves. The approximate continuations are dotted in. The points of intersection of these curves with the $CaCO_3$ solubility curve are of interest.

If the solution in contact with the soil consisted of pure $CaCO_3$, deposition of lime (in contradistinction to absorption) would commence at this point. As the liquid contains some $MgCO_3$ the point of deposition will be somewhere between the $CaCO_3$ and $MgCO_3$ curves. When the amount of lime used is only slightly in excess of soil acidity the deposition point will coincide absolutely with the magnesia curve (*see* Leather and Sen, *Memoirs of the Department of Agriculture, Chemical Series*, Volume III, No. 8). When lime is used in great excess it must approach the $CaCO_3$ curve. The curve showing deposition point is indicated roughly.

PART III. CONCLUSIONS.

The experiments have given us in the first place definite information regarding conditions under which lime is removed from or absorbed by soils of different types.

It is interesting to note that the absorption must take place in a similar manner whether it is the organic or the inorganic soil constituents which effect the absorption.

This result is of interest in connection with Hanley's experiments on acidity of peat soils (*loc. cit.*). The work has further indicated an interesting method for estimating the lime requirements of a soil.

It should be mentioned finally that the more usual form of absorption curve as worked out for potash could be roughly calculated for lime also from the data supplied here.

The direct experimental determination cannot be carried out without difficulty as it would involve maintenance of constant concentration of carbonic acid in solution throughout a whole series of experiments.

As the carbonic acid plays such an important part in the equilibrium attained with lime, the curves of Charts VIII and IX are perhaps more useful than the normal absorption curve would be.

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